International Journal of Applied Engineering Research ISSN 0973-4562 Volume 14, Number 19 (2019) pp. 3721-3729

Studies on Tribological characterization of Carbon Nanotube reinforced with 6061 Aluminium Alloy Metal Matrix Composites coated with Nickel

Srinivasan R [1,a)],H.K.Shivananad[2,b)]

[1]*Research scholar, Bangalore University, Bangalore-560001, Karnataka, India.*

[2]*Professor, Departmentof Mechanical Engineering, Bangalore University, Bangalore-560001, Karnataka, India.*

[a)]Corresponding author

Abstract

The objective of the study is to develop the appropriate materials having low density with high strength and modulus. MMC has been emerged as a promising material for structural and engineering applications for aerospace, automobile, engines and biomaterial devices. Carbon nanotubes (CNT)being a reinforcement material continue to surprise researchers with potential new applications and contributed towards a interesting discoveries of novel phenomena and properties of MMC. The development of MWCNT's reinforced Alumimium metal matrix composite specimens was done by stir casting method by tailoring the weight percentages of MWCNT's((0.5%,1%,1.5%,2%)) with Nickel deposition over surface by Electro less technique. The prepared specimens was subjected to wear tests using Pin-on-disc method. This study aimed to summarize the wear properties by accessing the effect of CNT reinforcements on wear rates of each specimens. From the tests results & SEM graphs, It was evident that with increase in CNT content the wear rate decreases till 1% of CNT, then it starts increasing again. The addition of CNT and coating of Nickel to Al 6061 matrix enhances the effective bonding between reinforcements and matrix by allowing the larger interfacial area of contact, and thereby increasing the wear resistance of the composite.

Keywords: MWCNT, Electro less, Pin-on-disc, Stir casting

1. INTRODUCTION

Metal matrix composites (MMCs) possess significantly improved properties including high specific strength, specific modulus, damping capacity and good wear resistance compared to the unreinforced alloys. Aluminum alloys [1,2] are used in many engineering applications due to their light weight and high strength characteristics. However, low hardness and consequently low wear resistance limit their use in some applications. Aluminum metal matrix composites (Al-MMCs) containing particulate reinforcements are considered as the promising solution for imparting better wear resistance to aluminum alloys.

The present paper discusses the study the investigation of a novel metal matrix composites by the incorporation of 6061 aluminum alloy matrix reinforced with CNT reinforcement material preferably (Multiwalled carbon nanotube)MWCNT's required to suit for particular application by tailoring the required properties by varying the appropriate weight percentages/vol % of CNT's. Due to their extraordinary properties(CNT), To overcome the hardness and wear characteristics of unreinforced alloys it is imperative to select a suitable MMC which has received suitable attention for the inclusion of CNT with the 6061 aluminum alloy metal matrix composites to obtain the desired properties. Al-MMC would achieve a high hardening index due to the inclusion of 6061 alloy (Al-Si-Mg)which is a precipitation hardened which influences the promising solutions for wear resistant applications. This has been experimentally investigated by various researchers to develop the new opportunities through evaluation of material characterization of aluminium based CNT composites in applications where dry sliding wear is significant.

In the case of MMCs, besides the mentioned effects of CNTs,wear reduction is often referred to as a hindered plastic deformation of the material due to the restricted movement of dislocations induced by the presence of CNTs[4]. Furthermore, reduced wear can be correlated to the grain refinement effect, thus inducing an increased hardness (Hall-Petch relation) [3]. Furthermore, it is important to mention that not only changes in the microstructure affect the tribological properties, but also the formation of interphases between CNTs and matrix material needs to be considered. In the literature, it is controversially discussed if there is a formation of interphases in a CNT-reinforced metal matrix composite, or rather when using which metal matrix [5]. When using nickel as the matrix material, no chemical reaction between Ni and CNTs can be observed [6,7]. Furthermore, nickel forms only metastable carbides under very specific conditions, therefore being suitable for a reinforcement based on CNTs with the parasitic emergence of interphases [8,9].

Recently, research has been extended to evaluate the effect of nanoparticles on wear resistance of aluminum and its alloys. One of the promising Nano reinforcements was carbon nanotubes (CNTs) which has exceptionally high mechanical properties [8,9]. Improvement of wear resistance of aluminum as a result of CNTs addition was reported in few studies [10-12]. Zhou and coworkers [10] fabricated aluminum composites reinforced with CNTs through pressure less infiltration of aluminum into CNTs– Mg–Al preformed in N 2 atmosphere at 800˚C. They found that CNTs were well dispersed and embedded in the Al matrix, the friction coefficient of the composite decreased with increasing the volume fraction of CNTs, and the wear rate of the composite decreased steadily with the increase of CNTs content (from 0 to 20 vol%).

Friction and wear characteristics of CNT composites were evaluated based on the dispersion condition, fabrication method, and CNT content [11The authors found that the best dispersion condition was performing the acid treatment, next, mixing aluminum powder and then performing ultrasonication for 20min. Also, they reported that the SPS method was more effective than the hot pressing(HP)method for minimizing the amount of wear and maintaining a stable friction. The spark plasma sintered composite with1wt%CNT(2vol%approx.) had the lowest friction and wear. Choi and coworkers [40] investigated the mechanical properties and wear characteristics of aluminum-based composites. They found that the well dispersed and aluminum atom-infiltrated multiwall carbon nanotubes (MWCNTs) formed a strong interface with the matrix by mechanical interlocking. The strength and wear resistance were significantly enhanced and the coefficient of friction was extremely reduced with the decrease of grainsize and the increase of CNT content. The optimum CNT content for minimum wear loss was reported as 4.5vol% (2wt%approx.). Also, they reported that the coefficient of friction and the wear rate increased with increasing the load and reduced with increasing the sliding speed. From the above studies [11-13], it is clear that the tribological properties of Al–CNT composites are highly sensitive to the CNT content, the method used for dispersing CNTs as well as the fabrication method used to consolidate the composite.

Deuis R.L et al., investigated Aluminum-silicon alloys and aluminum based metal matrix composites have found application in the manufacture of various automotive engine components such as cylinder blocks, pistons and piston insert rings where adhesive wear (or dry sliding wear) is a predominant process. For adhesive wear, the influence of applied load, sliding speed, wearing surface hardness, reinforcement fracture toughness and morphology are critical parameters in relation to the wear regime encountered by the material. In this review contemporary wear theories, issues related to counter face wear, and wear mechanisms are discussed [14].

Tribological properties of MM-CNT composites are evaluated using conventional techniques, like ball-on-disc [15, 16, pinon-disc [17–19], and ring-on-block techniques [20–22]. A ball-on-disc test involves application of a constant load on a ball (made of hard steel, tungsten carbide, or aluminum oxide) placed on the MM-CNT sample, while the sample is rotated at a selected speed. The tests can be carried out in air or in liquid medium. Wear phenomena is highly dependent on the type of mating surfaces, and comparisons must be made only for the same mating surfaces and geometry. It is important to measure the wear of MM-CNT composites in terms of volume loss instead of weight loss. Weight loss does not provide a real sense of the structural degradation of composite materials due to difference in the density between the CNT and metal matrix.

2. EXPERIMENTAL

2.1 Materials

Al 6061 with density 2.7 g/cm3, tensile strength 310 MPa (T6 condition) and modulus of elasticity 70 GPa was used as a matrix material. 6061 is a precipitation hardened aluminum alloy, containing magnesium and silicon as its major alloying elements. It has significant applications in aircraft, marine and automobile industries due to its good castability and corrosion resistance. The MWCNT's(Multi-walled carbon nanotubes) were used as the reinforcement material and procured from United Nanotech Innovations PVT Ltd., Bangalore, India. Nickel plating was done by electroless process over the composite surface in peenya industrial area, Bangalore Technical data of matrix and reinforcements (as received) are shown in Table 1 & 2.

Table 1: Properties of Al 6061

Elements	Si	Mn	Cr	Mg	Sn	Fe	Ti	Cu	Al
Amount (wt%)	0.477	0.048	0.191	0.864	0.063	0.463	0.008	0.307	Balance

Density	2.70 g/cm3
Young's modulus	68.9 Gpa
Tensile strength	124-290 Mpa
Elongation at break	12-25%
Poisson's ratio	0.33

Table 2: Properties of MWCNT:

Aspect ratio	-1000
Specifice surface area	SSA 350
Purity - wt%	>97%
Average Outer Diameter	20nm
Average Inner Diameter	5nm
Number of walls	5-15
Length	50 Micrometer

2.2 Method

Al6061 and multiwall carbon nano tubes (20-30 nm) were properly mixed for composition using stir casting process with a Stirrer speed of 300rpm was used to mix the MWCNT added for casting process.

2.3 Preparation of Composite specimens:

The CNT powder was initially purified to remove the impurities like graphite, amorphous carbon etc. by adding concentrated Nitric acid, filtering and washing with de-ionized water followed by drying at 1200 C. In stir casting process, MWNT of 0 wt%.0.5 wt. %, 1 wt. %, 1.5 wt. %, 2 wt. % was mixed with Al6061 for 20 min at 300 rpm to get uniform mixing in the crucible. The mixture of a particular weight percentage of MWCNT and Al6061 was molded in the pattern.

Fig, 2, 3 and 4. Liquid melt technique was used to fabricate the composite materials in which the CNT reinforcing materials were introduced into the molten metal pool through a vortex generated in the melt crucible by the use of an stainless steel stirrer which is rotating in the speed of 300rpm. The resulting mixture was tilt poured into the pre-heated permanent metallic molds. Using CNC lathe as cast specimen are machined to required dimensions from the cylindrical bar castings as per ASTM standard. Thus about specimen undergoes the process of nickel plating which takes in different stages which involves immersion in various alkaline bath to obtain clean surface, then they are dipped in nickel salt solution for the define amount of time as calculated based on the weight of the specimen dipped in it to obtain the uniform deposition of 40micron of nickel on the surface of the material.

The wear test was conducted using a pin-on-disc computerized wear testing machines shown in below fig in accordance with ASTM standardsG99-05.The surface finish of the specimens(Ra)2µm was rub bed again stahardened steel disc, which has a better surface finish of(Ra)0.2µm.The test uses the specimens of diameter of 6mm and length 35mm machined from the cast specimens. The wear tests were conducted using load so of 2kg. In steps of 2kg at 300rpm, 500 rpm and 700rpm. The test period was taken to be10minutes and the track radius selected was 50mm.The apparatus consists of a steel discof120 mm which forms the counter face on which the test specimen sort he pins slide over. The wear test was also conducted for the cast specimens of Aluminum alloy with varying percentage of CNT (0,0.5 wt. %, 1 wt. %, 1.5wt%, 2 wt. %)particulates at 40 micron nickel coating in a cast conditions were assessed for wear resistance.

Wear results are reported as volume loss in cubic millimeters for the pin and the disk separately. When two different materials are tested, it is recommended that each material be tested in both the pin and disk positions. The amount of wear is determined by measuring appropriate linear dimensions of both specimens before and after the test, or by weighing both specimens before and after the test. If linear measures of wear are used, the length change or shape change of the pin, and the depth or shape change of the disk wear track (in millimeters) are determined by any suitable metrological technique, such as electronic distance stylus profiling. Linear measures of wear are converted to wear volume (in cubic millimeters) by using appropriate geometric relations. Linear measures of wear are used frequently in practice since mass loss is often too small to measure precisely. If loss of mass is measured, the mass loss

Figure 1 CNT

Figure 2 Stir casting

Figure 3 moulding

Figure 4 final castings

value is converted to volume loss (in cubic millimeters) using an appropriate value for the specimen density.

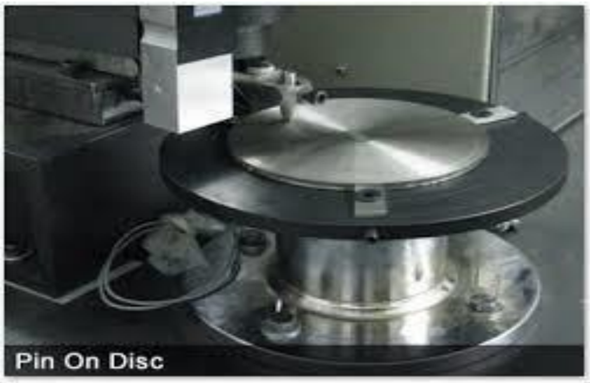


Figure 5: pin-on-disc test apparatus

Figure 6: pin specimen & hardened steel disc (Before and after machining)

Wear rate = V/S

Where

i) **V= Volume of wear m3=v1-v2**

$V1=\pi\ ^2L1$ $V2=\pi\ ^2L2$

r = Radius of specimen L1=Initial length of specimen L2=Final length of specimen

ii) **S=Sliding distance (meter) =π*D*N*T=2*π*R*N*T**

D= Diameter of wear track in meter R=Radius of wear track in meter N=Speed of the wheel in rpm T=Sliding time in minutes

iii) **Wear rate (mm3/m) =V/S**

V= Volume of the wear in debris in mm3

S=Sliding in meter

With the help of length we can calculate Volume,

<u>Initial Volume (V1):</u>

<u>Final Volume (V2 :</u>

Volume Difference: = V1-V2 mm3

Sliding Distance in Meter(S): = **π*D*N*T**

Wear rate = (V1-V2)/S mm3/m

3. RESULTS

3.1 For 2Kg load at 300rpm

Load = 2kg

Speed = 300 rpm

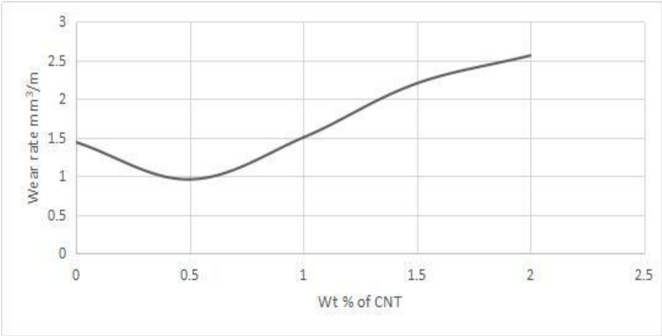
Track diameter = 50mm

Time = 5 minutes

Sliding Distance = = 3.14*50*300*5 = 235.6194 m

TABLE 4: for 2kg load at 300rpm

Material	**Diameter mm**	**Initial length L1 mm**	**Final Length L2 mm**	**Initial Volume V1 mm^3**	**Final volume V2 mm^3**	**Volume difference V1-V2 mm^3**	**Wear rate $*10^{-3}$ mm^3/m**
0%	6	35	34.88	989.6017	986.2088	3.39292	1.44
0.5%	6	35	34.92	989.6017	987.3397	2.261946	0.96
1%	6	35	34.87	989.6017	986.0674	3.534291	1.5
1.5%	6	35	34.81	989.6017	984.4181	5.183627	2.2
2%	6	35	34.78	989.6017	983.5698	6.031857	2.56



Graph 1: Wear Rate at 2kg load at 300rpm

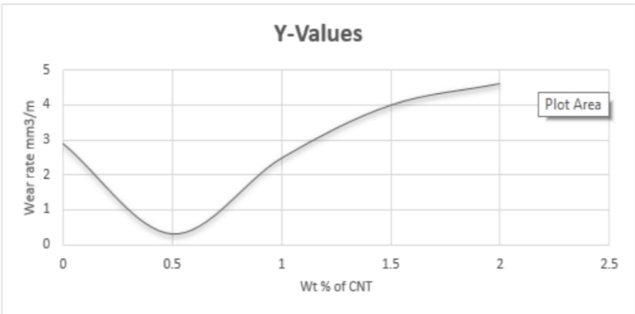
The above Graph1 depicts the highest wear rate was exhibited at 2% of CNT and least wear rate was at 0.5% of CNT. From graph it is clear that with increase in CNT content the wear rate decreases till 1% of CNT, then one it start increasing again. The wear rate has reduced to 33% by using CNT and coating of Nickel to Al 6061 MMC.

3.2 For 2Kg load at 500rpm:

Sliding Distance = = 3.14*50*500*5 = 392.6991 m

Table 5: for 2kg load at 500rpm

Material	Diameter mm	Initial length L1 mm	Final Length L2 mm	Initial Volume 3 V1 mm	Final volume 3 V2 mm	Volume difference V1-V2 mm^3	Wear rate $*10^{-3}$ 3 mm /m
0%	6	35	34.60	989.73	978.4188	11.3112	2.880373
0.5%	6	35	34.96	989.73	988.5989	1.13112	0.288037
1%	6	35	34.66	989.73	980.0696	9.660397	2.46
1.5%	6	35	34.45	989.73	974.1006	15.62942	3.98
2%	6	35	34.36	989.73	971.6658	18.06416	4.6



Graph 2: Wear Rate at 2kg load at 500rpm

The above Graph2 depicts highest wear rate was exhibited at 2% of CNT and least wear rate was at 0.5% of CNT. From graph it is clear that with increase in CNT content the wear rate decreases till 1% of CNT, then one it start increasing again. The wear rate has reduced to 80% by using CNT and coating of Nickel to Al 6061 MMC.

3.3 For 2Kg load at 700rpm

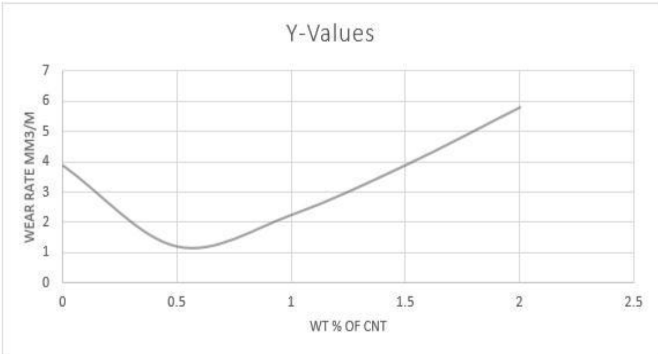
Sliding Distance=

=3.14*50*700*5=549.7787 m

Table 6: for 2kg load at 700rpm

Material	Diameter mm	Initial length L1 mm	Final Length L2 mm	Initial Volume V1 mm^3	Final volume 3 V2 mm	Volume difference V1-V2 mm^3	Wear rate *10 -3 mm^3/m
0%	6	35	34.16	989.6016859	966.0083	21.33141	3.88
0.5%	6	35	34.66	989.6016859	980.067	6.7073	1.22
1%	6	35	34.12	989.6016859	964.7203	12.44071	2.26285714
1.5%	6	35	34.06	989.6016859	963.0709	21.44137	3.9
2%	6	35	33.73	989.6016859	953.7561	31.88717	5.8

The below Graph3 depicts highest wear rate was exhibited at 2% of CNT and least wear rate was at 0.5% of CNT. From graph it is clear that with increase in CNT content the wear rate decreases till 1% of CNT, then one it start increasing again. The wear rate has reduced to 68% by using CNT and coating of Nickel to Al 6061 MMC.



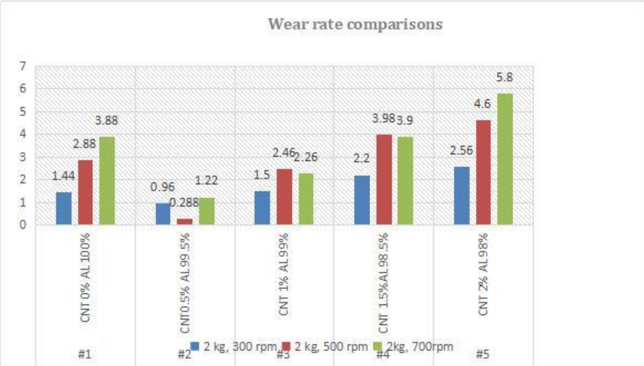
Graph 3: Wear Rate at 2kg load at 700rpm

Table 7: Wear rate of different specimens

Speicmens	Compositions	2 kg, 300 rpm	2 kg, 500 rpm	2kg, 700rpm
#1	CNT 0% AL 100%	1.44	2.88	3.88
#2	CNT0.5% AL 99.5%	0.96	0.288	1.22
#3	CNT 1% AL 99%	1.5	2.46	2.26
#4	CNT 1.5%AL 98.5%	2.2	3.98	3.9
#5	CNT 2% AL 98%	2.56	4.6	5.8

3.4 Wear rate comparisons

The below Graph 4 depicts wear rate of A6061 CNT reinforced composite with Nickel Coating different CNT composition (0%, 0.5%.1%, 1.5% and 2%) at different RPM (300rpm , 500 rpm and 700rpm) at 2kg load .The highest wear rate was exhibited at 2% of CNT and least wear rate was at 0.5% of CNT. From graph it is clear that with increase in CNT content the wear rate decreases till 1% of CNT, then it start increasing again.



Graph 4: Wear Rate at 2kg load at different rpm

5. MICRO-EXAMINATION :

Samples from worn-out surfaces of five discs specimens used for the study are subjected to SEM analysis. The below figs.depict the worn surfaces of Al 6061 alloy, Al reinforced with 0.5%, 1.0%, 1.5% and 2.0 % vol. of MWCNT at Sliding speed of 300rpm,500rpm and 700rpm under 20N load and sliding distance of 235.6194 m, 392.6991 m & 549.7787 m with similar magnification. SEM Micrographs of the worn surface of the stir casted composite specimens (at a load of 2kg (20 N) revealed that the wear tracks have made it possible to analyse that the path is not homogeneous and a non-uniform wear was noticed which was showing wear outstanding zones and areas with grooves along the sliding direction subjected to plastic deformation after a sliding speed of 300,500 and 700rpm. Based on the SEM study, It was observed that the wear debris was formed due to the plastic flow of matrix.

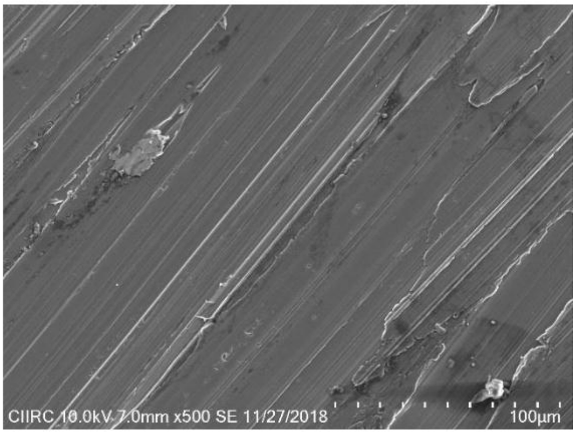


Fig-7 : Worn out surface of pure 6061 aluminium alloy

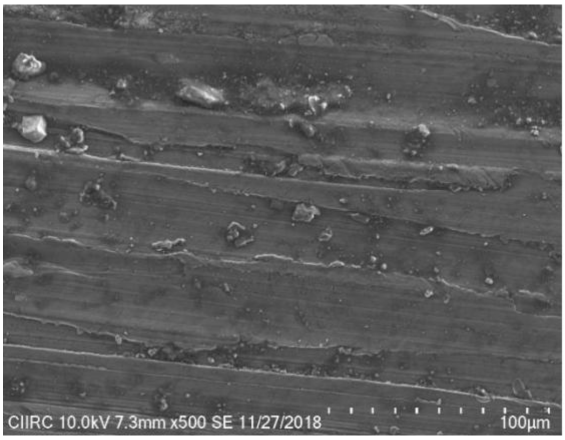


Fig-8: Worn out surface of 6061 aluminium alloy reinforced with 1% CNT under 500rpm

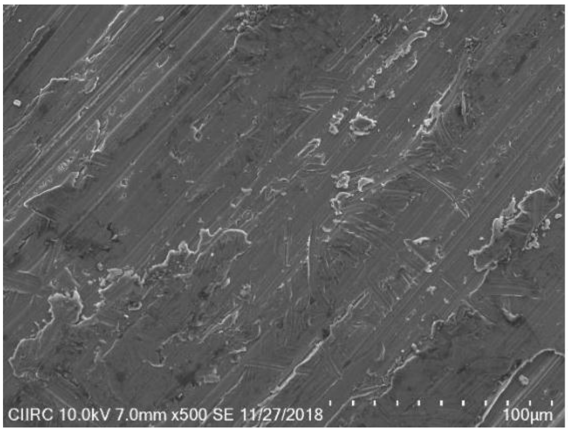


Fig-9: Worn out surface of 6061 aluminium alloy reinforced with 1% CNT under 700rpm

Fig-10: Worn out surface of 6061 aluminium alloy reinforced with 1.5% CNT under 300rpm

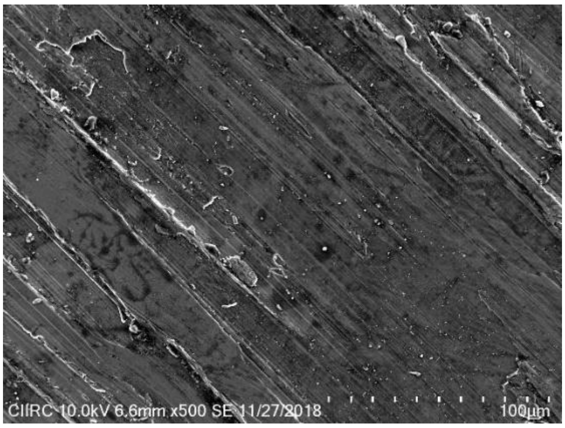


Fig-11: Worn out surface of 6061 aluminium alloy reinforced with 1.5% CNT under 500rpm

Fig-12: Worn out surface of 6061 aluminium alloy reinforced with 1.5% CNT under 700rpm

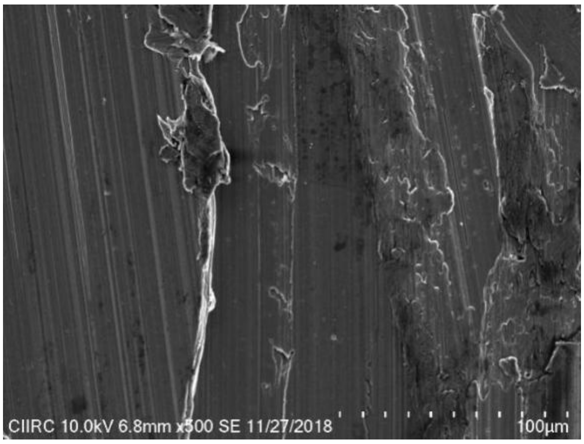


Fig-13: Worn out surface of 6061 aluminium alloy reinforced with 2% CNT under 300rpm

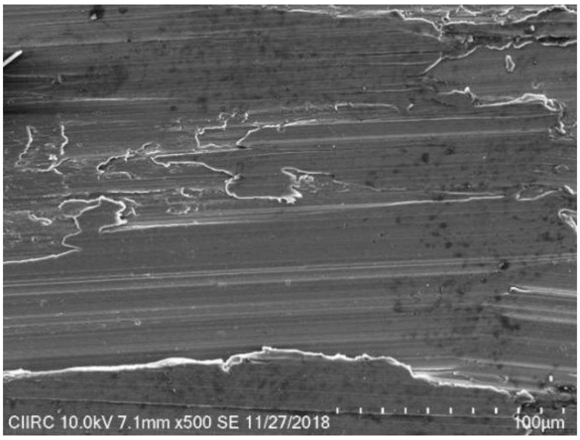


Fig-14: Worn out surface of 6061 aluminium alloy reinforced with 2% CNT under 700rpm

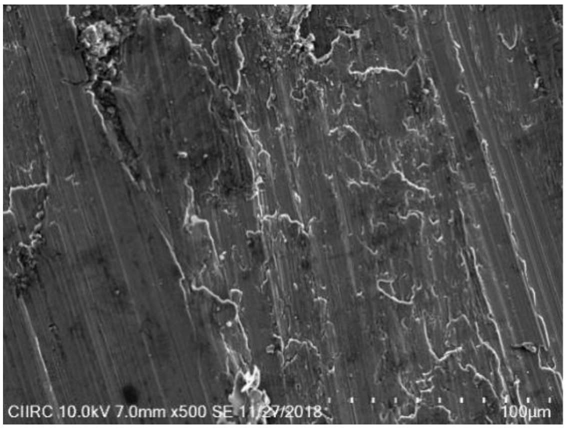


Fig-15: Worn out surface of 6061 aluminium alloy reinforced with 2% CNT under 500rpm

6. CONCLUSIONS

It is clearly concluded from the tests results and graph, that with increase in CNT content the wear rate decreases till 1% of CNT, then it start increasing again. The addition of CNT and coating of Nickel to Al 6061 matrix enhances the effective bonding between reinforcements and matrix by allowing the larger interfacial area of contact, and thereby increasing the wear resistance of the composite. Wear rate are influenced by normal load, reinforcement ratio and sliding speed. Wear resistance is been effective when the CNT contents appears below 2% weight within the composition of Al alloy6061. Above the increased weight of reinforcement content will slightly decrease the surface microhardness which tends to increase the wear rate and wear debris is formed by mechanical cracking of grains or delamination of tribo-films on the scale of the grain size.The wear mechanism is characterized as mild wear at lower reinforcement ratio, severe wear at moderate reinforcement ratio, and ultra-fine wear at higher reinforcement ratio.

REFERENCES

[1] N. Saheb, T. Laoui, A.R. Daud, M. Harun, S. Radiman, R. Yahaya, "Influence of Ti addition on wear properties of Al–Si eutectic alloys" Wear249 (2001) 656–662.

[2] N. Saheb, T. Laoui, A.R. Daud, R. Yahaya, S. Radiman"Microstructure and hardness behaviors of Ti-containing Al–Si alloys", Philosophical Magazine A 82 (2002) 803–814.

[3] Suárez, S.; Rosenkranz, A.; Gachot, C.; Mücklich, F "Enhanced tribological properties of MWCNT/Ni bulk composites –Influence of processing on friction and wear behaviour". Carbon2014, 66, 164–171. [CrossRef]

[4] Chen, X.H.; Chen, C.S.; Xiao, H.N.; Liu, H.B.; Zhou, L.P.; Li, S.L.; Zhang, G"Dry friction and wear characteristics of nickel/carbon nanotube electroless composite deposits"Tribol. Int. 2006, 39, 22–28.

[5] Bakshi, S.R.; Agarwal, A. "An analysis of the factors affecting strengthening in carbon nanotube reinforced aluminum composites". Carbon 2011, 49, 533–544.

[6] Hwang, J.Y.; Neira, A.; Scharf, T.W.; Tiley, J.; Banerjee, R. "Laser-deposited carbon nanotube reinforced nickel matrix composites. Scr. Mater. 2008, 59, 487–490.

[7] Suarez, S.; Soldera, F.; González Oliver, C.; Acevedo, D.; Mücklich, F. "Thermomechanical Behavior of Bulk Ni/MWNT Composites Produced via Powder Metallurgy. "Adv. Eng. Mater. 2012, 14, 499–502.

[8] S.Iijima, "Helical microtubules of graphitic carbon", Nature354(1991)56–58 .

[9] E.W.Wong,P.E.Sheehan,C.M.Liebert, "Nanobeam mechanics: elasticity, strength, and toughness of nanorods and nanotubes, "Science277(1997) 1971–1975.

[10] S.Zhou,X.Zhang,Z.Ding,C.Min,G.Xu,W.Zhu, "Fabrication and tribological properties of carbonnano tubes reinforced Al composites prepared by pressureless infiltration technique, Composites PartA:Applied Science and Manufacturing" 38(2007)301–306.

[11] I.Y.Kim, J.H.Lee, G.S.Lee, S.H.Baik, Y.J.Kim, Y.Z.Lee, "Friction and wear characteristics of the carbonnanotube–aluminum composites with different manufacturing conditions,"Wear267(2009)593–598.

[12] H.J.Choi,S.M.Lee,D.H.Bae, "Wear characteristic of aluminum-based composites containing multi-walled carbon nanotubes,"Wear270(2010)12–18.

[13] Kuzumaki T, Miyazawa K,Ichinose H, Ito K (1998),"Processing of carbon nanotubes reinforcedaluminium composite" Vol.139,pp.2445-2449.

[14] Deuis, Subramanian &Yellupb (1996), "dry sliding wear of aluminium composites-a review" vol.57, pp.415-435.

[15] Chen, X. H., Peng, J. C., Li, X. Q., Deng, F. M., Wang, J. X., and W. Z. Li. 2001. "Tribological behavior of carbon nanotubes—reinforced nickel matrix composite coatings." J. Mater. Sci. Lett. 20: 2057–2060.

[16] Liu, B., Zeng, Z., and Y. Lin. 2009. "Mechanical properties of hard Cr–MWNT composite coatings." Surf. Coat. Technol. 203: 3610–3613.

[17] Tu, J. P., Zhu, L. P., Chen, W. X., Zhao, X. B., Liu, F., and X. B. Zhang. 2004." Preparation of Ni-CNT composite coatings on aluminum substrate and its friction and wear behaviour." Trans. Nonferrous Met. Soc. China 14(5): 880–884.

[18] Tu, J. P., Yang, Y. Z., Wang, L. Y., Ma, X. C., and X. B. Zhang. 2001. "Tribological properties of carbon-nanotube-reinforced copper composites."Tribol. Lett. 10(4): 225–228.

[19] Zhou, S. M., Zhang, X. B., Ding, Z. P., Min, C. V., Xu, G. L., and W. M. Zhu. 2007. "Fabrication and tribological properties of carbon nanotubes reinforced Al composites prepared by pressureless infiltration technique." Composites A 38: 301–306.

[20] Chen, W. X., Tu, J. P., Wang, L. Y., Gan, H. Y., Xu, Z. D., and X. B. Zhang. 2003. "Tribological application of carbon nanotubes in a metal-based composite coating and composites." Carbon 41: 215–222.

[21] Dong, S. R., Tu, J. P., and X. B. Zhang. 2001. "An investigation of the sliding wear behavior of Cu-matrix composite reinforced by carbon nanotubes." Mater. Sci. Eng. 313: 83–87.

[22] Chen, X., Zhang, G., Chen, C., Zhou, L., Li, S., and X. Li. 2003. "Carbon nanotube composite deposits with high hardness and high wear resistance. "Adv. Eng. Mater. 5(7): 514–518.

[23] Fiorito, S. 2008. Carbon Nanotube: Angels or Demons? Singapore: Pan Stanford Publishing.

[24] Shivanand.H.K , Mahagundappa M Benal , 2006 "Effects of reinforcements content and ageing durations on wear characteristics of Al (6061) based hybrid composites" Elsevier -Wear 262 (2007) 759–763.

[25] A. Wang, H.J. Rack, Abrasive wear of silicon carbide particulate and whisker reinforced 7091 aluminium matrix composites, Wear 146 (1991) 337.

[26] C.S. Lee, Y.H. Kim, K.S. Hanand, T. Lim, Wear behavior of Aluminium matrix composites, J. Mater. Sci. 27 (1992) 793.

[27] S.J. Lin, K.S. Liu, Effect of ageing on abrasion rate in an Al–Zn–Mg–SiC composite, Wear 121 (1988) 1.

[28] A. Wang, H.J. Rack, The effect of ageing on the abrasion behavior of SiCw/2124, in: Metal and Ceramic Matrix Composites: Processing, ModelingandMechanicalBehavior,TheMineral,Metalsa ndMaterialsSociety, 1990.

[29] J.H.Shyong, C.Ruiz,P.M. Mummery, B.Derby, The Relationship Between Microstructure and Mechanical Properties of Particulate Reinforced Metal Matrix Composites, MMC Institute of Metals, London, 1991.

[30] Dorri Moghadam, A.; Omrani, E.; Menezes, P.L.; Rohatgi, P.K. Mechanical and tribological properties of self-lubricating metal matrix nanocomposites reinforced by carbon nanotubes (CNTs) and graphene—A review. Compos. Part B Eng. 2015, 77, 402–420.